MULTI-SENSOR ORDNANCE SIGNATURES FOR ALGORITHM DEVELOPMENT AND MODEL TRAINING

H. H. Nelson and J. R. McDonald
Chemistry Division, Code 6110
Naval Research Laboratory
Washington, DC 20375-5342

and

Richard Robertson
Hughes Associates, Inc.
Columbia, MD 21045

ABSTRACT

The Naval Research Laboratory is developing a Multi-Sensor Towed Array Detection System, *MTADS*, for ordnance detection and site characterization. One component of this task is construction and validation of algorithms for target characterization and location for use in the data analysis system. In support of this task, we have collected an extensive set of ordnance signatures using total field magnetometers, total field magnetometers deployed as vertical gradiometers and specially modified Geonics EM-61 pulsed induction sensors. The ordnance items characterized range from Mk 42 submunitions to Mk 82, 500 lb bombs at depths ranging from the surface to 20 ft. Where appropriate, signatures are recorded as a function of azimuth and inclination. We discuss the details of the sensor systems and the data collection methodologies. Typical signatures are presented and compared to simple models. We anticipate that this data set will become one of the standards for passive and active sensor algorithm development and training in the ordnance detection community.

INTRODUCTION

The Naval Research Laboratory, under a program funded by the Environmental Security Technology Certification Program, ESTCP, (Marqusee, 1996) is developing the Multi-sensor Towed Array Detection System, *MTADS*, for ordnance detection and site characterization. A primary goal of this program is to provide a field demonstration of a towed array sensor system that uses state-of-the-art technologies for automated detection of Ordnance and Explosive Waste (OEW). To achieve this goal, we have assembled a field-worthy system consisting of advanced, real-time, centimeter-level GPS location and guidance, a sophisticated data acquisition system, arrays of total field magnetometers and pulsed induction sensors and an advanced Data Analysis System, DAS. The *MTADS* system will be field tested and demonstrated at several sites.

In an earlier report (McDonald and Robertson, 1996) we reported on a sensor evaluation study that led to the selection of the individual sensors to be used in the *MTADS* system arrays. As mentioned above, the chosen sensors have been integrated into a working demonstration system. In addition to fielding the correct sensor hardware however, the usefulness of the *MTADS* system also depends on the ability of the data analysis system to accurately process the raw sensor data and derive a listing of ordnance positions, depths and sizes with minimal false positives. The basic physics of this process is well understood in principle; we have reported successful modeling of the signals produced by several test objects previously (Barrow et al., 1996). A real-world data analysis system however, has to deal with noisy, possibly truncated input data and should be tested using signatures of real ordnance. Thus, we have collected an extensive set of ordnance signatures using the *MTADS* sensors for use in evaluation and refinement of the *MTADS* DAS and as a benchmark for the training of other analysis systems. In this report, we present a discussion of the data collection methodology, the individual ordnance items tested and present typical ordnance signatures. The entire data set has been prepared as a set of ASCII files and can be obtained by contacting the authors.

SENSOR ARRAYS AND *MTADS* DATA ACQUISITION

The magnetometers used in the *MTADS* arrays are Geometrics Model 822, selected for low heading error and sensor-to-sensor offset. They are designated 822 ROV by the manufacturer. When used in the total field magnetometer mode, the sensors are arranged in a linear array 1.75 m wide with a horizontal sensor spacing of 0.25 m. The sensors can be set to heights of 0.25, 0.40 or 0.55 m from the surface. The data reported here were collected with a sensor height of 0.25 m. In the gradiometer configuration, the sensors are arranged as four pairs of vertical gradiometers. The horizontal spacing is 0.5 m with a vertical spacing of 0.55 m. This results in a total array width of 1.5 m.

In both cases, the sensor arrays are mounted on the *MTADS* passive tow platform which maintains the sensor arrays at a distance of 4.9 m behind the tow vehicle. The total ferrous content of the vehicle has been carefully controlled to minimize directional offsets at the sensors during a survey. The measured North-South offset for the *MTADS* system is approximately ± 5 nanotesla. For the data reported here, all surveys were collected driving south to north on every line to eliminate this effect.

Total field magnetometer data are obtained by processing the raw magnetometer Larmor frequency using Geometrics G-822A counters, and this information is transmitted to the Data Acquisition Computer as a serial stream. In both total field and gradiometer mode, all eight total field readings are recorded. The vertical gradient is computed later by the Data Analysis System. Magnetometer data is collected at 50 Hz. Combined with our typical survey rate of 3 m/s, this corresponds to a sampling interval of 6 cm in the direction of travel. This allows us to completely characterize signatures with a spatial wavelength ≥ 12 cm. Thus, for items more than about 15 cm deep, we can resolve the signature in the direction of travel. The total field magnetometer spacing is 25 cm so the spatial resolution perpendicular to the direction of travel is lower by a factor of 4.

The pulsed induction sensors are modified Geonics EM-61 sensors. The modifications are intended to make the sensors compatible with vehicular towing and increase the sensitivity to small objects. To accomplish the first of these, we increased the transmit pulse repetition frequency, decreased the analog time constant and increased the digitizer sampling rate. Sensitivity has been improved by increasing the amplifier gain and moving the sampling gate closer to the transmit pulse.

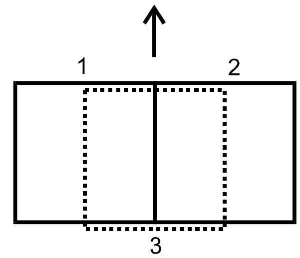


Figure 1. Positions of the EM-61 sensors in the *MTADS* array.

The 1-m square EM-61 sensors are deployed in an overlapping array of three as shown schematically in Figure 1. The middle sensor is displaced slightly both above and behind the two outer sensors. Distance from the tow vehicle is also an issue with the pulsed induction sensors. The *MTADS* active tow platform positions the EM-61 sensors 3.1 m from the tow vehicle. EM-61 receiver coil signals are converted to a serial stream using a Geonics *MTADS* EM-61 electronics package and are transmitted to the Data Acquisition computer. These data are stored as a gain factor and an upper and lower coil amplitude for each of the three sensors. The maximum sample rate for the EM-61 sensors is 10 Hz. We typically survey with these sensors at a speed of 1.5 m/s. This results in a spatial sampling interval of 15 cm, well within the 1 m width of the coils.

GPS positions are provided by a Trimble 4000SSi GPS receiver operating in the Real-Time-Kinematic, On-The-Fly resolution of integer ambiguities (RTK/OTF) mode. The reported RTK positions are routinely good to ±5 cm. GPS positions are reported once per second and the positions of the intermediate sensor readings are interpolated from these. The recorded GPS positions and interpolated tracks for a total field magnetometer run are shown in Figure 2. All input data (including platform heading and attitude and vehicle dead reckoning data) are time-tagged with millisecond resolution for later correlation with the GPS derived positions.

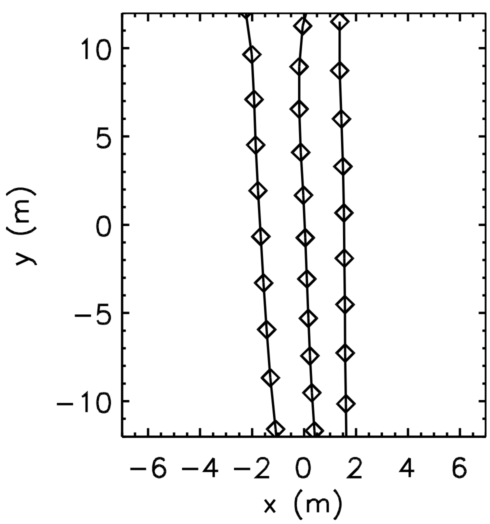


Figure 2. Recorded GPS positions and interpolated paths for a typical survey.

SIGNATURE COLLECTION

Ordnance Items Tested

The individual ordnance items that comprise the training data set were chosen to be representative of the range of ordnance encountered in the field. The depths tested were chosen based on the range of penetration depths observed for each item. A range of azimuth and inclination was chosen to characterize the ability of the Data Analysis System to fit these variables. The conditions used for the total field data sets are listed in Table 1. The corresponding information for the gradiometer and EM-61 surveys is listed in Table 2.

Table 1. Ordnance items, depths and orientations used for the total data set.

Item	Depths	Azimuth	Inclination
20 mm projectile	surface	0°, 90°	0°
30 mm projectile	surface	0°, 90°	0°
M42 grenade	surface, 15 cm	0°, 90°	0°
M46 submunition	surface, 15 cm	0°, 90°	0°
60 mm mortar	0.25, 0.5 m	45° steps	45° steps
81 mm mortar	0.5, 0.75, 1 m	45° steps	45° steps
105 mm projectile	0.5, 0.75, 1 m	45° steps	45° steps
5" rocket	1, 1.5 m	45° steps	45° steps
250 lb bomb	2, 3.5 m	90° steps	90° steps
500 lb bomb	2, 3.5, 5.5 m	90° steps	90° steps

Table 2. Ordnance items, depths and orientations used for the gradiometer and EM-61 data sets.

Item	Gradiometer Survey			EM-61 Survey	
	Depths	Azimuth	Inclination	Depths	Azimuth & Inclination
20 mm projectile	surface	0°, 90°	0°	surface	0°, 90°
30 mm projectile	surface	0°, 90°	0°	surface	0°, 90°
M42 grenade	surface, 15 cm	0°, 90°	0°	surface, 15 cm	0°, 90°
M46 submunition	surface, 15 cm	0°, 90°	0°	surface, 15 cm	0°, 90°
60 mm mortar	0.25 m	45° steps	45° steps	0.25, 0.5, 0.75, 1 m	90° steps
81 mm mortar	0.5, 0.75 m	45° steps	45° steps	0.5, 0.75, 1 m	90° steps
105 mm projectile	0.5, 0.75 m	45° steps	45° steps	0.5, 0.75, 1, 1.25 m	90° steps
5" rocket	1 m	45° steps	45° steps	0.5, 1, 1.5 m	90° steps
155 mm projectile				1.5, 2 m	90° steps

A test facility was established at the Chesapeake Bay Division of the Naval Research Lab in Chesapeake Beach, MD. A surface site, a 1-m deep hole and a 7-m deep well were established and precisely surveyed. Test jigs were constructed to hold the ordnance items at the predetermined depths and orientations. A set of measurements for each ordnance item with each sensor suite was then collected. In addition, background measurements were collected before and after each set of total field measurements. These background surveys were used to correct the measured signatures for the naturally occurring variations at the site. This process will be discussed in detail in the next section.

RESULTS

Magnetometer Data

The magnetic background at our test site is not uniform; it contains magnetic gradients from several local features. The survey site exhibits a marked slope downward from the NW corner to the SE corner. Each day's background runs were fit to a plane through the equation Signature(x,y) = Ax + By. For the data collected on Julian day 323 of 1996, the fitted coefficients were A = -1.45 nanotesla/meter and B = -3.03 nanotesla/meter. Both of these coefficients have an uncertainty of ~10%. When this background is subtracted from the measured data, the true ordnance signatures are obtained. The signatures from a 105 mm mortar with azimuths of 0, 45, 90 and 180° , an inclination of 0° and a depth of 0.5 m are shown in Figure 3. As expected, the observed moment

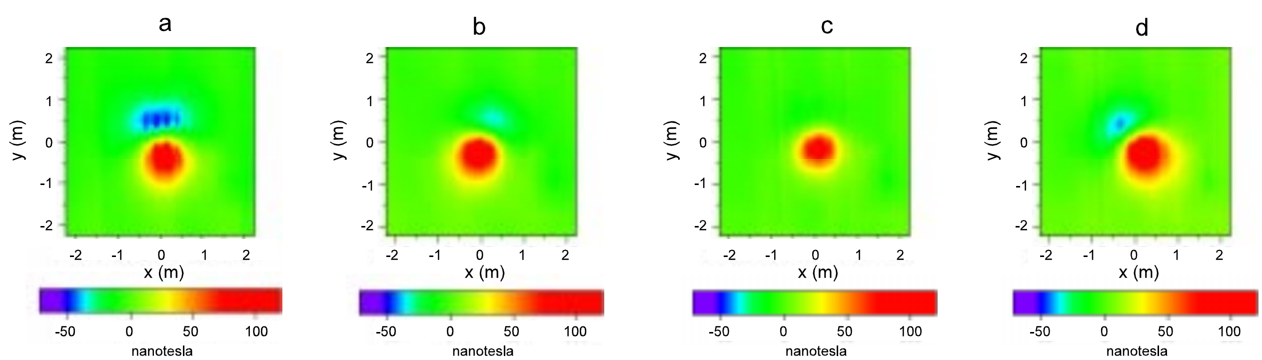
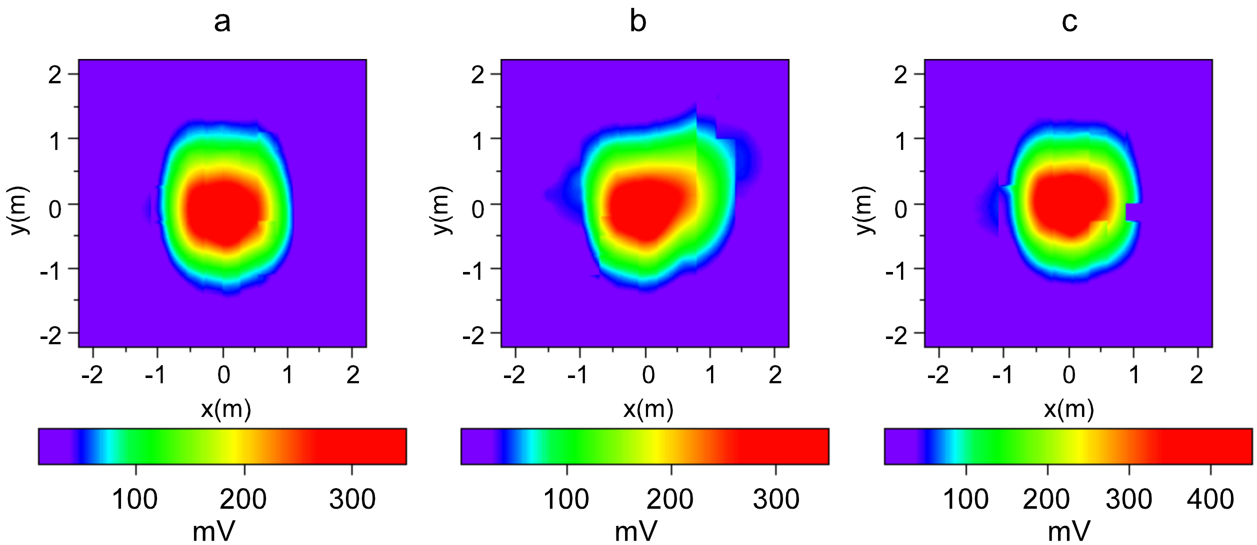


Figure 3. Measured total field signatures from a 105 mm projectile at a depth of 0.5 m, an inclination of 0° and azimuth of a) 0°, b) 45°, c) 90° and d) 135°.

is aligned with the body axis of the projectile when the azimuth is 0 and 45° but shifts to the short axis when the projectile is rotated to 90°.

EM-61 Data

The pulsed-induction sensors are much less sensitive to geological interference than the magnetic measurements, so background subtraction is not required for the EM-61 data sets. At each position, receiver response amplitudes are available from both the upper and lower coils of the EM-61. These two signals can be examined individually, differenced to suppress the response from items on the surface or combined for a total model match. The measured upper coil signatures for a 105 mm projectile at 0.5 m depth are shown in Figure 4. As is evidenced by the increased saturation in panel (c) of the figure, the signature measured when the projectile is oriented vertically is substantially more intense than when the object is oriented in the plane of the surface. This is due



to the upper half of the item being closer to the coils in the vertical case. In some of the signatures

Figure 4. Measured EM-61 upper coil signatures from a 105 mm projectile at a depth of 0.5 m and an azimuth and inclination of a) 0°, 0°, b) 90°, 0° and c) 0°, 90°.

we have collected, there is a noticeable spreading of the observed signal when the ordnance item is oriented perpendicular to the direction of travel of the array. We are currently examining the possibility of exploiting this asymmetry for orientation determination.

Data Format

All ordnance signatures have been archived as ASCII files in an x, y, intensity format. The EM-61 files contain two intensity entries per position, corresponding to the upper and lower coils. Each file contains a header line that describes the ordnance item, depth and orientation tested. A complete set of these files can be obtained by contacting the authors.

SUMMARY

We have collected total field magnetometer, vertical gradiometer and pulsed-induction ordnance signatures as a function of depth and orientation. The measured total field data has been corrected for the background at the test site. The resulting signatures are available as ASCII files from the authors. We anticipate that this data set will become one of the standards for passive and active sensor algorithm development and training in the ordnance detection community.

REFERENCES

Barrow, B., Khadr, N. DiMarco, R. and Nelson, H. H., 1996: “The Combined Use of Magnetic and Electromagnetic Sensors for the Detection and Characterization of UXO”, *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems*, Keystone CO, April 1996, p 469 - 477

Marqusee, Jeffrey, 1996, The ESTCP Website address is http//www.acq.osd.mil/ens//ESTCP.hmtl

McDonald, J. R. and Robertson, R., 1996: "Sensor Evaluation Study for Use with Towed Arrays for UXO Site Characterization", *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems*, Keystone CO, April 1996, p 451 - 463